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Salinity

Soluble salt and exchangeable cation concentrations play major roles in determining the pH, physical characteristics, and chemical composition of soils. When a salt dissolves in water, it dissociates or separates into cations and anions. The predominant cations in salt-affected soils are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}); the predominant anions are chloride (Cl^{-}), sulfate (SO_4^{2-}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^{-}).

Clays and organic matter contain negative electrical charge sites. In salt-affected soils, this charge is satisfied by calcium, magnesium, sodium, and potassium ions. These cations, bound to the exchange sites by the electrical charges, are known as exchangeable cations because they can be removed from the charged surface only by replacement with another cation from the soil solution. *See Humus; Soil chemistry.*

Classification. Each soil can be classified as normal, saline, sodic, or saline-sodic, based on its salt content and exchangeable cation ratios.

Normal soils. These soils do not contain sufficient soluble salts to reduce crop yield or sufficient exchangeable sodium to affect soil physical properties adversely. A special technique is employed to measure the salt content of the soil. A saturation paste is made by mixing just enough distilled water with a soil sample to fill the voids without having excess water standing on the surface of a well-mixed sample after 4–16 h. An extract is obtained by removing the solution by vacuum suction through a filter. This saturation paste extract is measured for electrical conductivity (EC_e), which is related to the soluble salt content. For a normal soil the value is less than 4 mmhos/cm. The exchangeable sodium percentage (ESP) of the total exchangeable cations is less than 15. For a normal soil the sodium adsorption ratio (SAR) is less than 13. It is calculated from the concentration, in mmoles/liter, of extract cations [Eq. (3)]. The pH of the saturated soil paste is less than

$$\mathrm{SAR} = \mathrm{Na}^{+}/(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})^{-1/2} \quad (3)$$

8.3. These are defined upper limits, but if salt-sensitive crops were grown on soils with an electrical conductivity of 3.5 mmhos/cm, a significant yield reduction would be expected. Likewise, using a high-volume sprinkler system to irrigate a soil with an exchangeable sodium percentage of 12 could produce serious runoff rates because of low infiltration rates. *See Hydrolysis; pH.*

Saline soils. These soils contain sufficient soluble salts (electrical conductivity greater than 4 mmhos/cm) in the upper root zone to reduce yields of most cultivated crops and ornamental plants. The exchangeable sodium percentage is less than 15, the sodium absorption ratio is less than 13, and the pH is less than 8.3. The predominant cations are calcium, magnesium, and, in a few cases, potassium. The predominant anions are chloride and sulfate. Water entry and movement through these soils is not inhibited by exchangeable sodium. Osmotic effects and chloride toxicity are the predominant causes of plant growth reduction. *See Osmosis.*

Sodic soils. These soils are lower in soluble salts than saline soils (electrical conductivity less than 4 mmhos/cm). The exchangeable sodium percentage is greater than 15 and the sodium absorption ratio of the saturation paste extract is greater than 13. The pH of the saturation paste is greater than 8.5. Bicarbonate, carbonate, and hydroxide (OH^{-}) ions are the anions that predominate in these soils; they cause calcium to precipitate from solution as calcium carbonate ($CaCO_3$; lime). The combination of high exchangeable sodium percentage and pH, and low electrical conductivity causes the clay and organic matter to disperse, which in turn destroys the soil structure or tilth, causing so-called slick spots. These spots have extremely low rates of water and air exchange. They often have a black, greasy, or oily-looking surface due to the dispersed organic matter; vegetation may be absent because water infiltration is low.

Saline-sodic. These soils are similar to saline soils in that the electrical conductivity is greater than 4 mmhos/cm and the pH is below 8.3. Saline-sodic soils differ from saline soils in that more than 15% of the exchangeable cations is sodium and the saturation-paste sodium absorption ratio is greater than 13. The anions are a mix of bicarbonate, chloride, and sulfate. As long as the electrical conductivity remains above 4 mmhos/cm, infiltration rates and hydraulic conductivities are similar to those of normal or saline soils. Irrigating saline-sodic soils with water having low concentrations will convert them into sodic soils if they do not contain gypsum (a calcium sulfate mineral). This happens as the electrical conductivity decreases without a decrease in the exchangeable sodium percentage, causing the undesirable properties of sodic soils to be expressed. It is not uncommon to have a mix of two or more classes of salt-affected soils within a field. Salt-affected soils tend to be highly variable from one part of a field to another.

Sources. Most soluble salts and exchangeable cations are derived from rock and mineral weathering of the soil parent materials. In high-rainfall, humid, and tropical areas, rain and melting snow leach the salts from the soil as they form. In arid and semiarid areas, the annual evapotranspiration potential is greater than the total annual precipitation, and the salts are not always leached from the soil as they are released. With time, they may accumulate in the root zone at concentration levels that affect plant growth.

Salts often accumulate above shallow water tables as water moves to the soil surface by capillary rise (wicking) and evaporates, leaving the salts on or near the surface. Shallow water tables may occur naturally, induced by irrigating poorly drained areas, by irrigating upslope from lowlands, or by construction activity that blocks natural subsurface lateral drainage.

All natural waters contain dissolved salt. In many arid and semiarid areas, good-quality irrigation water (low in salts and low in sodium) is not available; consequently, water is used that contains more salts or sodium than is desirable. If sufficient water does not move through the soil and leach the salts below the root zone, salts or sodium will accumulate in the soil. It is often stated that under irrigation "hard water makes soft soils and soft water makes hard soils." This implies that irrigation waters containing predominantly calcium and magnesium salts (sodium absorption ratio less than 3 or 4) tend to promote a more friable soil condition than do waters with high concentrations of sodium.

Four conditions must be satisfied in order to remove soluble salts and excess sodium from soils: (1) less salt must be added to the soil than is removed; (2) salts must be leached downward through the soil; (3) water moving upward from shallow water tables must be removed or intercepted to avoid additional salts moving back to the soil surface; and (4) in sodic and saline-sodic soils the exchangeable sodium must be replaced with another cation, preferably calcium, and the sodium leached out. Applications of soil amendments (gypsum, iron sulfate, sulfur, or sulfuric acid) are beneficial only on sodic soils when leaching also occurs and on leaching of saline-sodic soils that do not contain gypsum.

Saline and sodic soils are found primarily in arid and semiarid areas of the world. Exceptions are recently drained coastal areas, salt marshes, and soils formed in depressions from marine deposits where the weathering products are not leached from the soil. Aridisols and Entisols include most salt-affected soils. Low rainfall and unweathered soil materials result in insufficient salts leaching from the root zone. Mollisols, Alfisols, and Vertisols also contain considerable saline and sodic soil areas.

Human activities such as spills or intentional dumping of salts or solutions from drilling-mud ponds, mines, food-processing plants, municipal sewage water, power-plant cooling-tower water, or heavy applications of wood ash can induce saline and sodic conditions in any soil when soluble salts are applied faster than they are leached from the soil.

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